A9

Surface Acoustic Wave Magnetic Field Sensors

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Motivation and Objectives

Surface Acoustic Wave (SAW) Sensor

Advantages: high bandwidth

→ many application scenarios

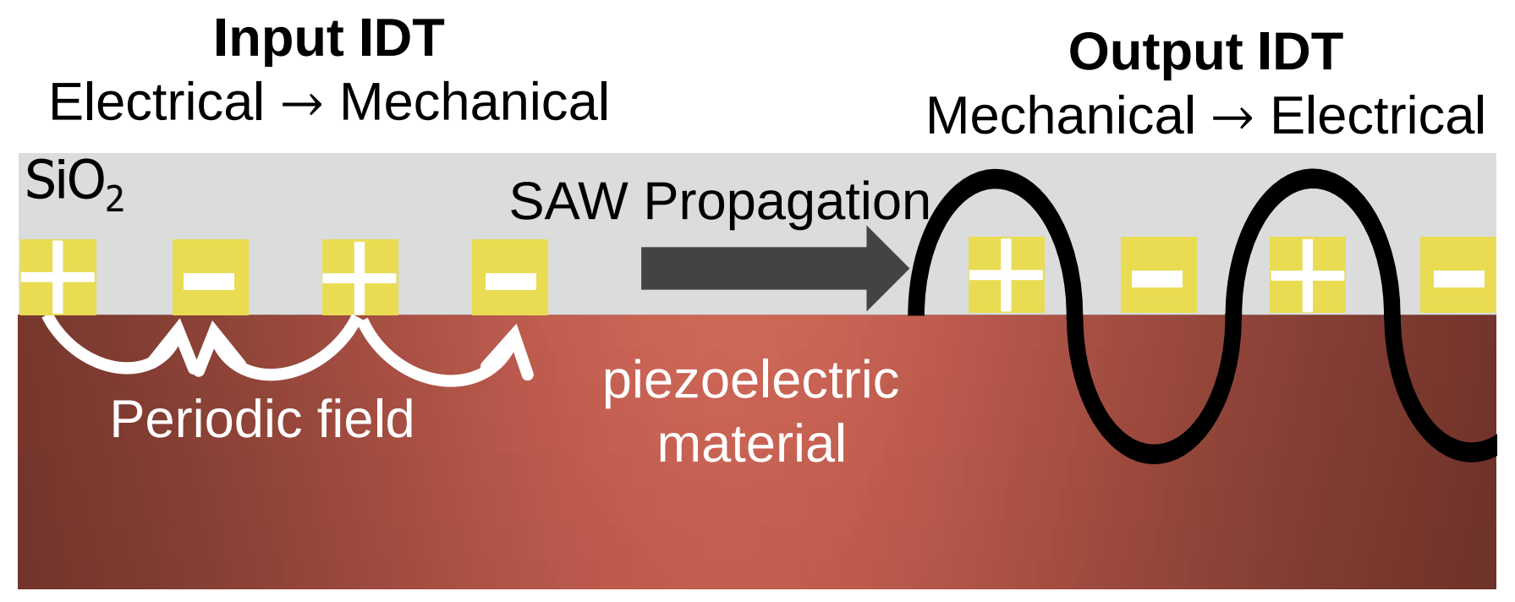
Miniaturization possible

Challenges: High frequencies

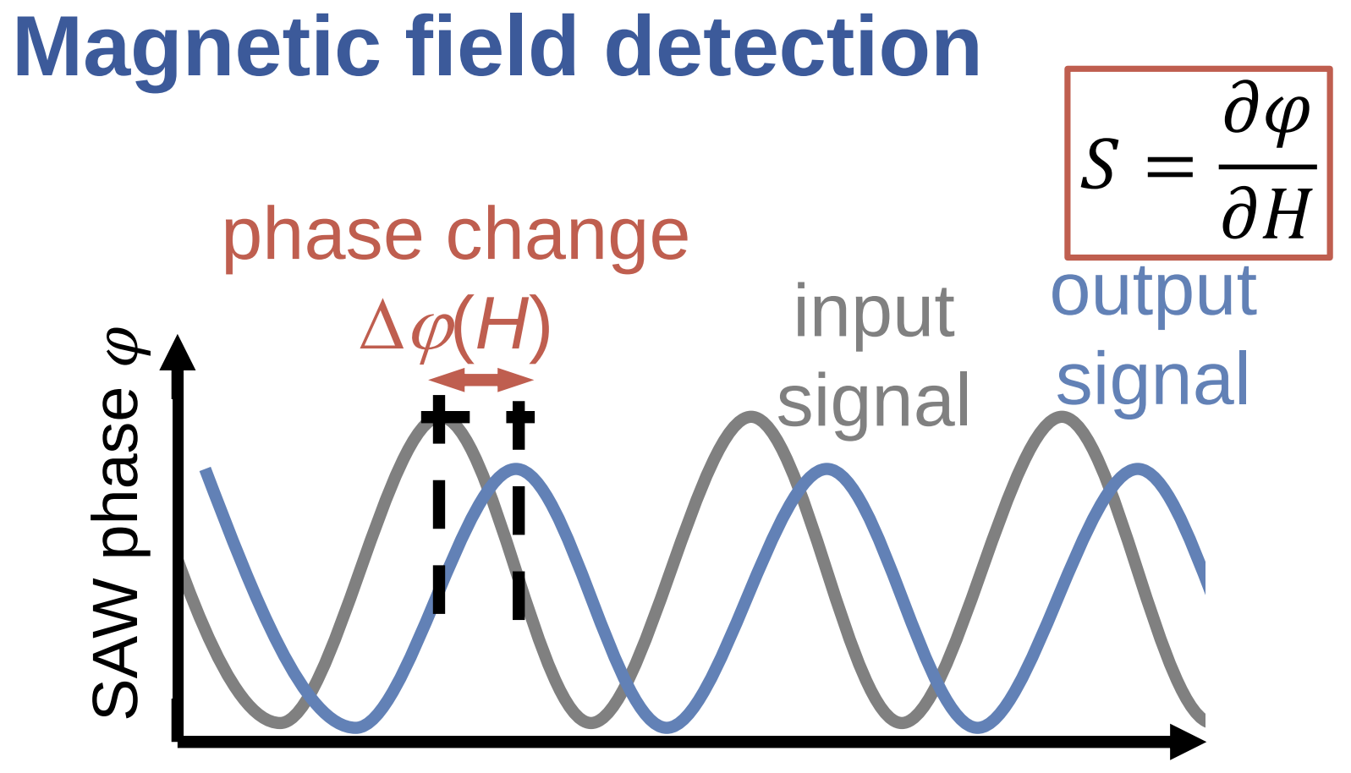
→ new film developments

→ electronics development

SAW Generation



Magnetic field detection

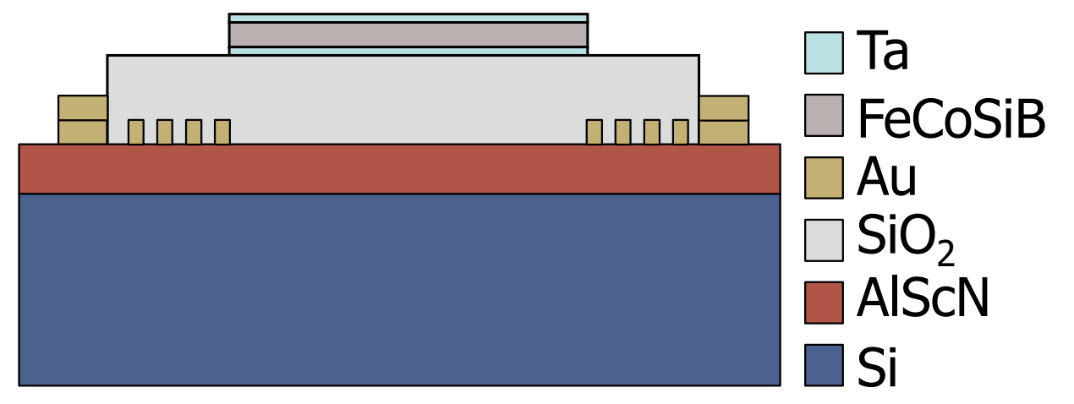


$$S = \frac{\partial\varphi}{\partial H}$$

Measurement principle is based on the magneto-elastically induced change of Young's modulus of the magnetostrictive layer (ΔE effect).

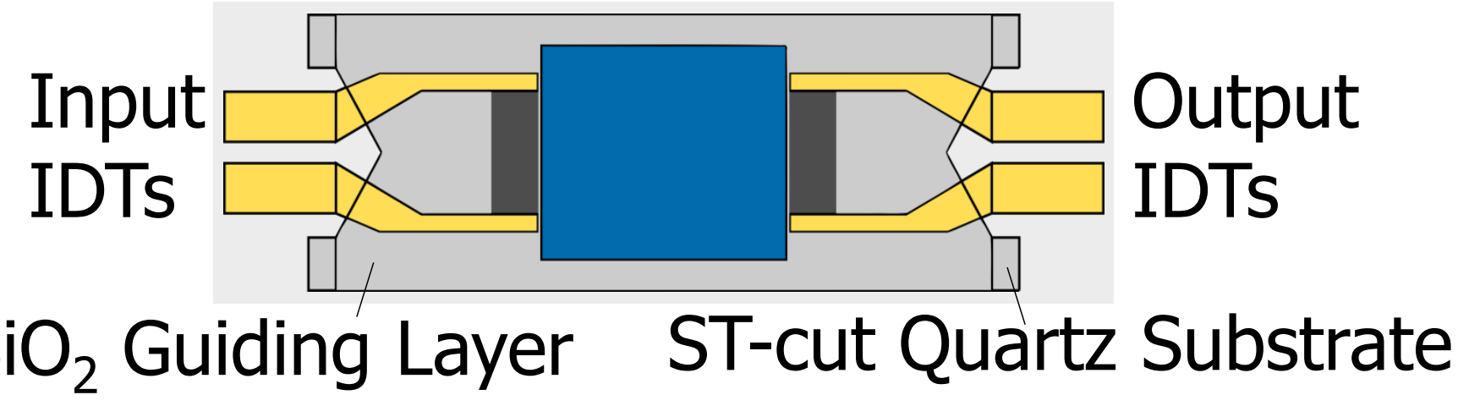
Thin-film AlScN SAW sensor (ISIT)

- AlScN on 200 mm Si wafers
- CMP smoothed SiO_2 (several SAW modes)
- single layer $(Fe_{90}Co_{10})_{78}Si_{12}B_{10}$



Single Crystal SAW sensor (CAU)

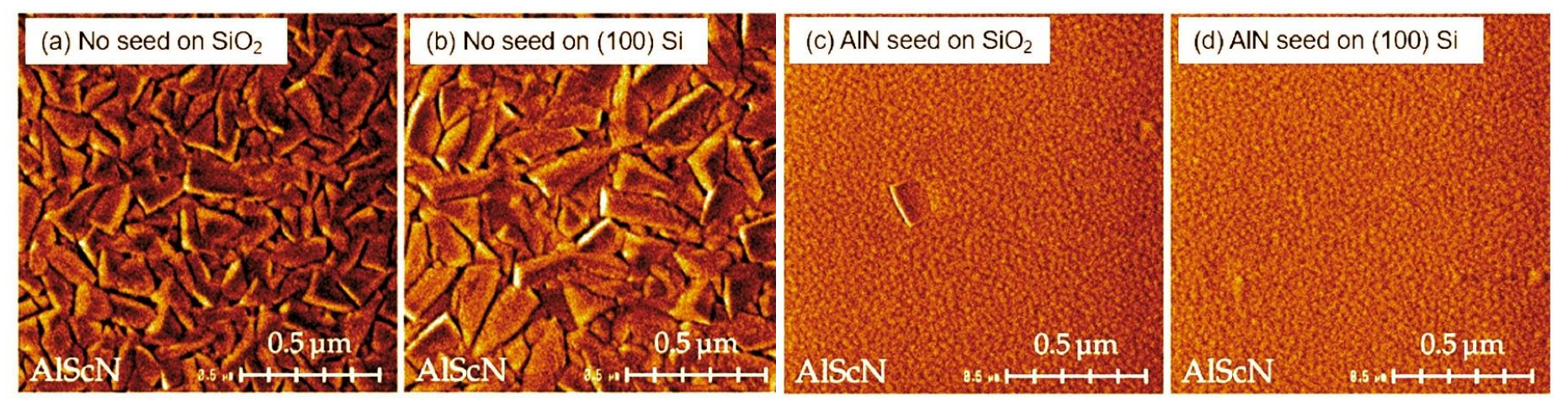
- Piezoelectric substrate
- SiO_2 guiding layer (**Love wave**)
- exchange biased $(Fe_{90}Co_{10})_{78}Si_{12}B_{10}$



Results of the Second Funding Period

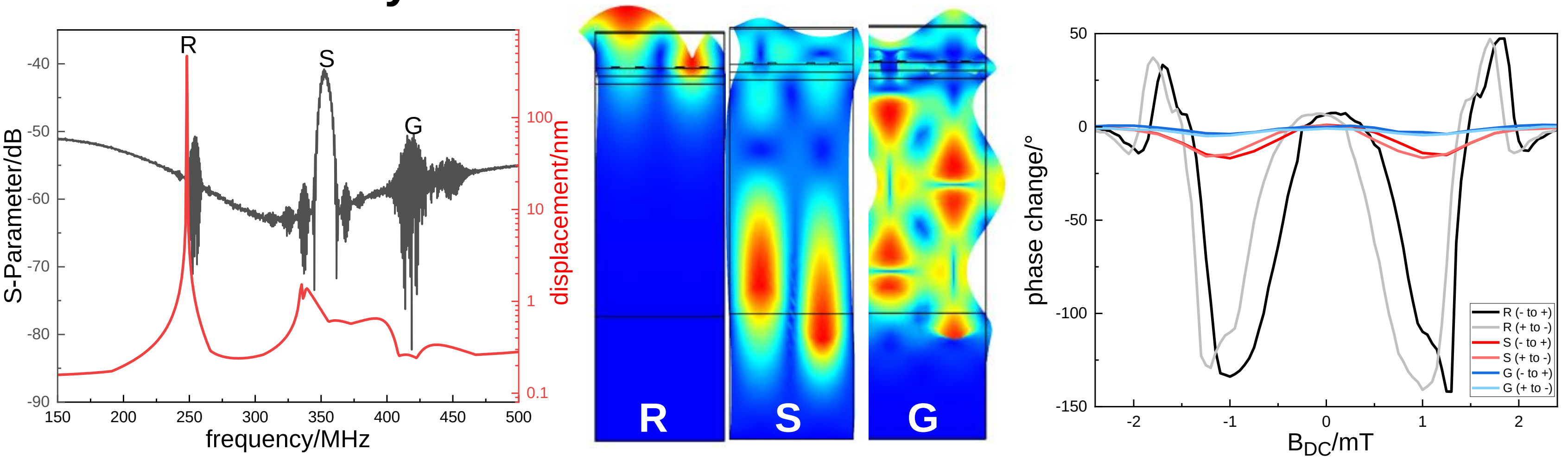
Thin film AlScN SAW sensor (ISIT)

AlScN deposition on Si



AlN seed layer significantly increases the layer growth (*c*-axis quality, piezo-acoustic coupling) [A9-4]

SAW modes in layered SAW structures



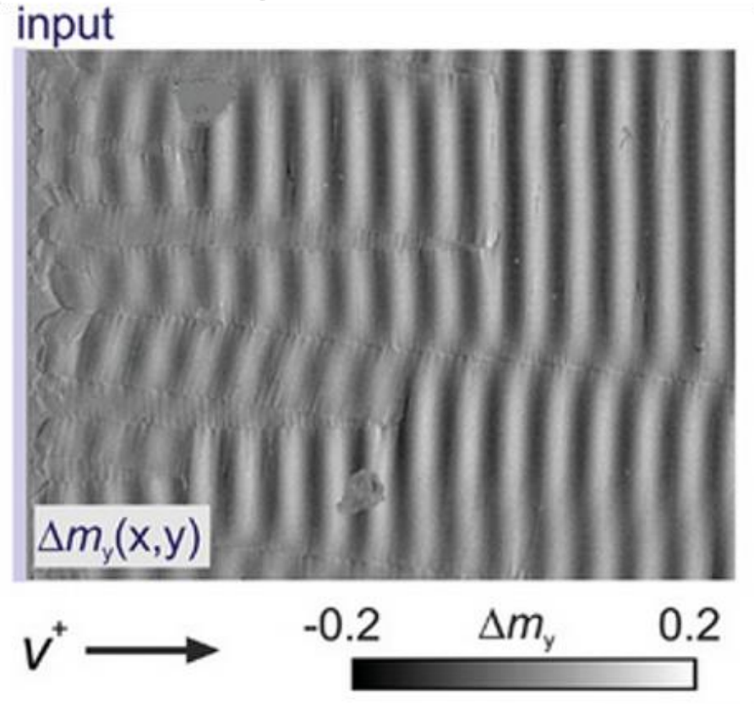
The **Rayleigh** (R) mode, **Sezawa** (S) mode and other higher order **guided** (G) modes are observed and investigated for magnetic field sensing.

Sensor performance with single layer FeCoSiB

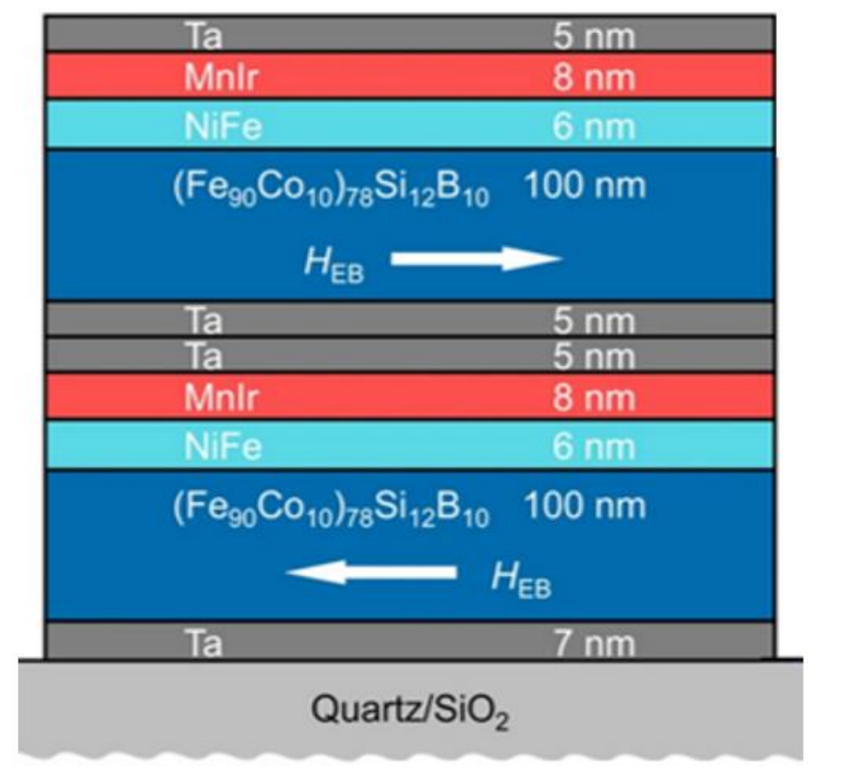
Sensitivity: 1200 °/mT **LoD:** 350 $pT/Hz^{1/2}$ at 10 Hz

Single Crystal SAW sensor (CAU)

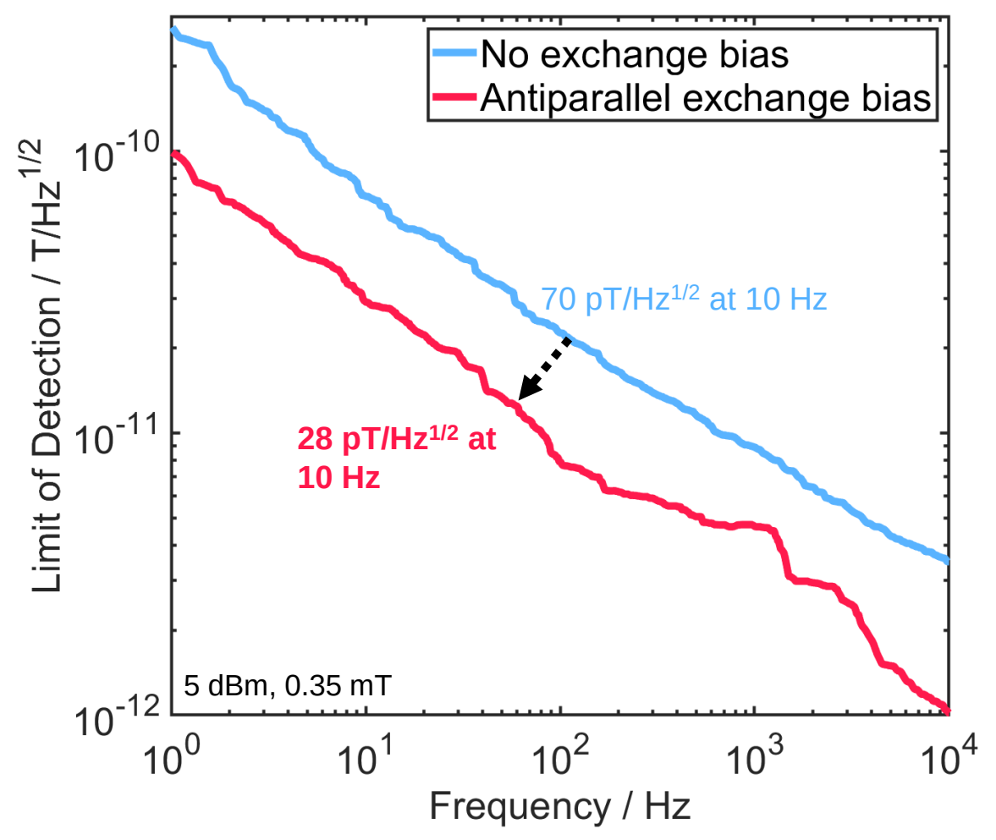
Exchange bias



Domain walls
→wavefront dephasing
→major noise source

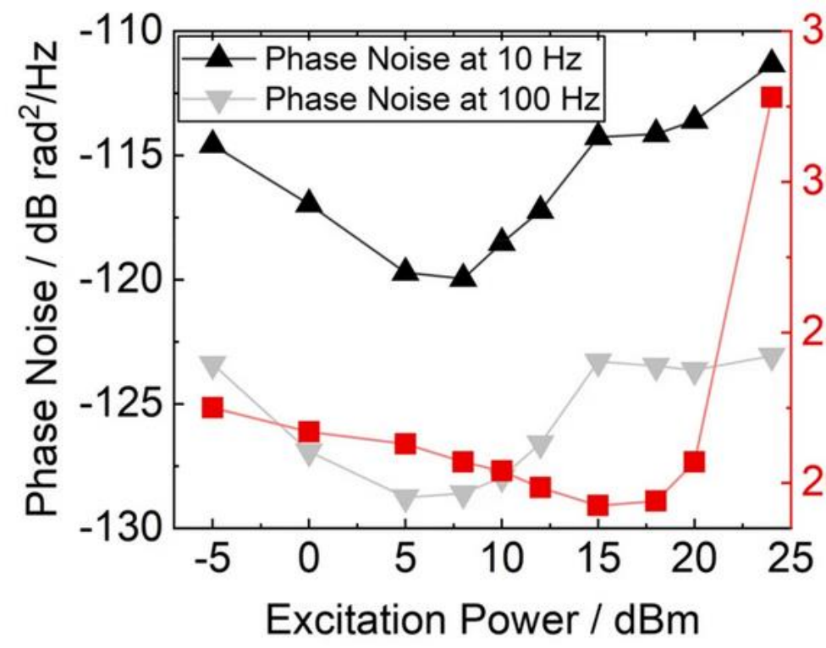


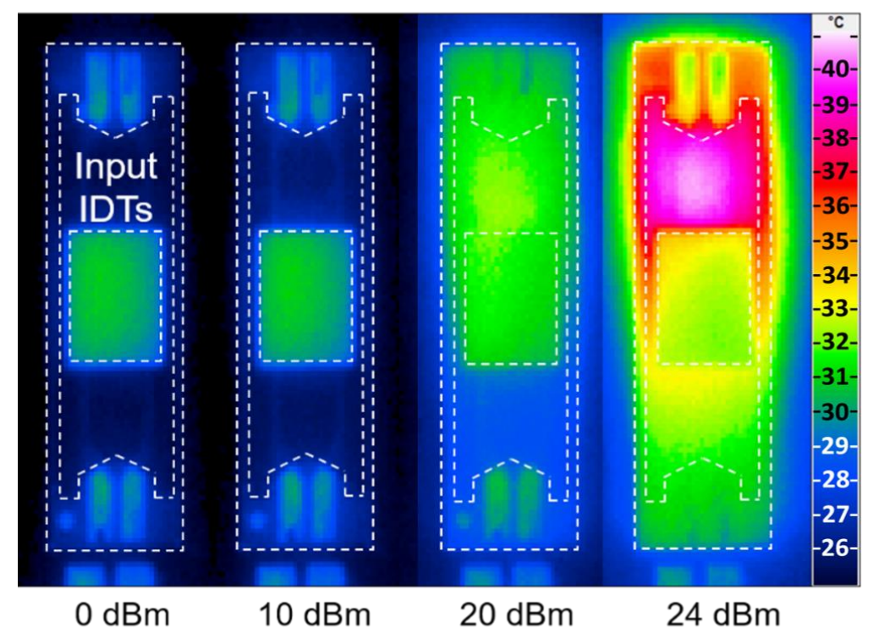
Anti parallel exchange bias → one domain



2.5x LoD improvement [A9-3, A9-7]

Optimal excitation power





Sensitivity and phase noise depent on excitation power

Lowest LoD at 5dBm [A9-7]

Work Plan for Third Funding Period

Research methods: Clean room fabrication

1000 qm ISIT cleanroom

300 qm CAU cleanroom

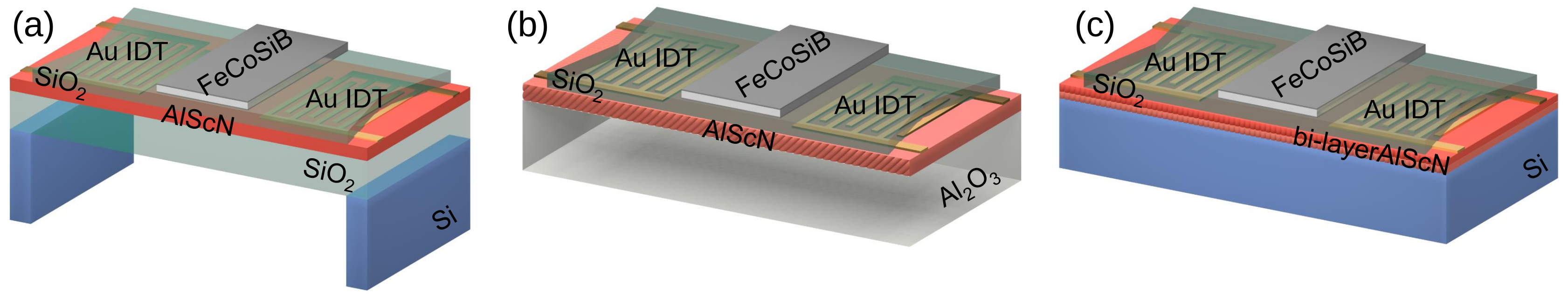
- SAW fabrication
- Functional characterization
- Structural characterization

Work plan

WP1 Magnetic multilayer stacks

- Enhance exchange bias stacks for thin film SAW
- Anisotropy alignment for bias-free operation

WP2 – Thin-film SAW



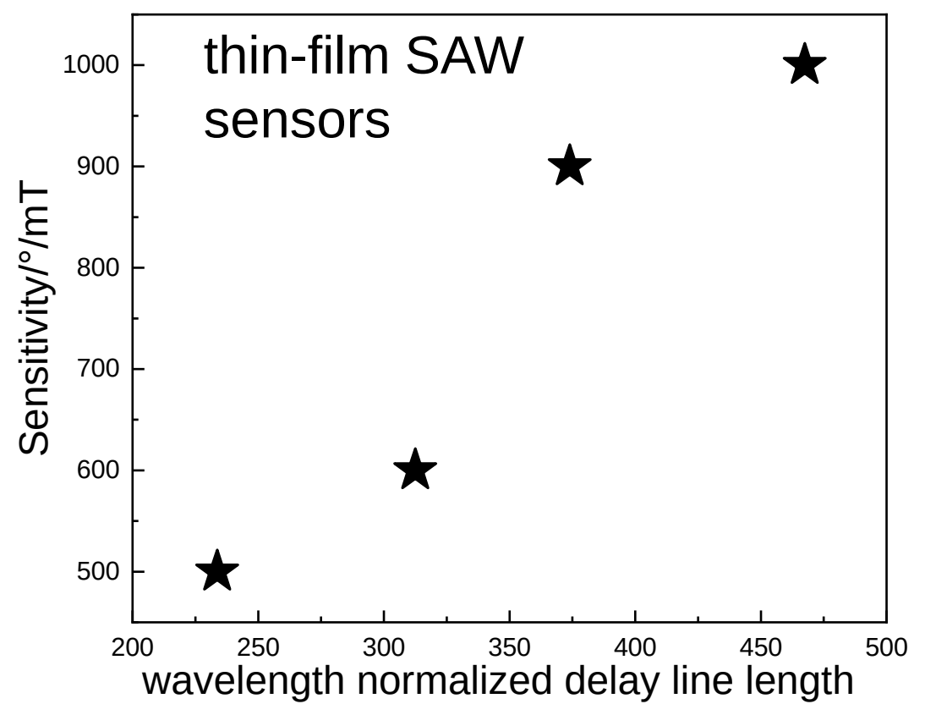
Backside substrate etch

AlScN grown with tilted c-axis on sapphire

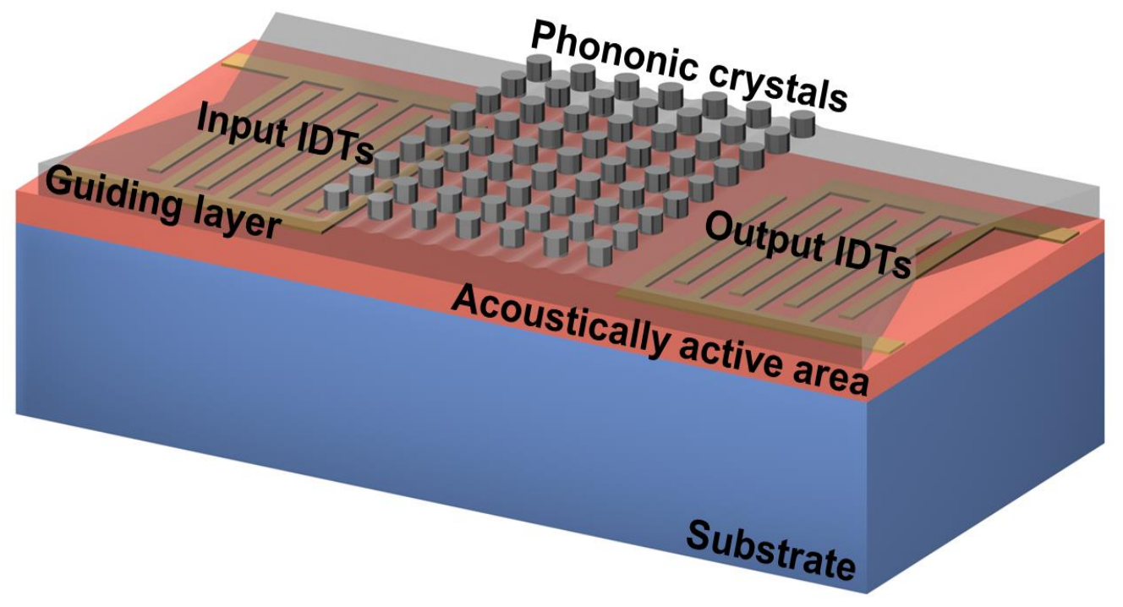
AlScN bi-layer grown on a Si substrate

WP3 Single Crystal SAW

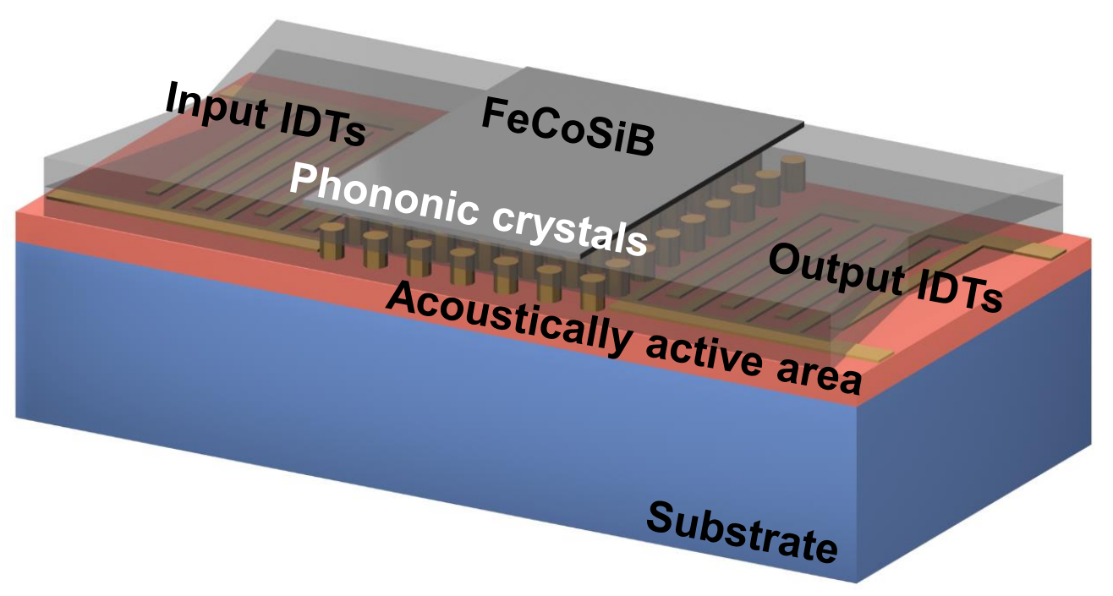
- Research on optimal SAW carrier frequency for the LOD
- Sensitivity improves at higher frequency
- Noise increases near ferromagnetic resonance?



WP4 Phononic Crystals



Different approaches to fabricate phononic crystals

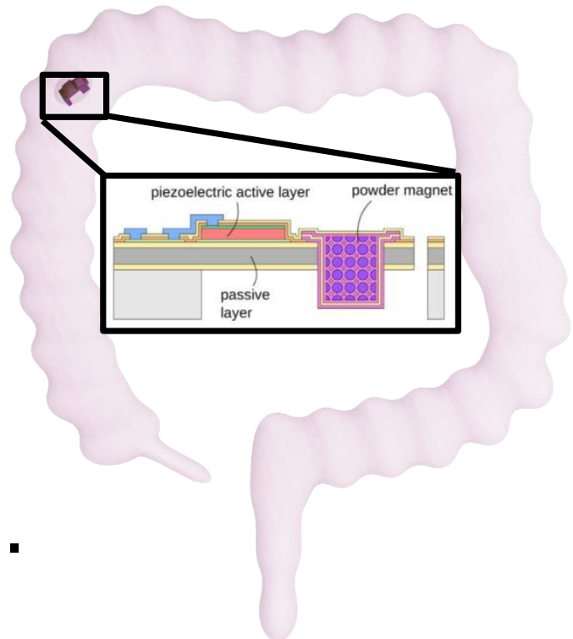


Improving sensitivity by creating resonant modes aligned with SAW modes resulting in enhanced interaction. [A9-10]

WP5 Integration in biomedical application

- Providing sensors and measurement experise
- SAW perfect fit due the broadband capabilities

B13(N): Localization of current wireless motility capsules.



🟦 ISIT 🟥 CAU 🟪 Both

		2024		2025				2026				2027				2028	
		3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
WP1 – Magnetic multilayer stacks	Exchange bias	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪								
	Zero bias					🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪				
WP2 – Thin-film SAW	Acoustic layer							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Substrate variations	🟦	🟦	🟦	🟦	🟦	🟦										
	Application magnetic stacks									🟦	🟦	🟦	🟦	🟦	🟦		
WP3 – Single Crystal SAW	Frequency investigation	🟥	🟥	🟥	🟥	🟥	🟥										
	Design variation					🟥	🟥	🟥	🟥	🟥	🟥						
	Application magnetic stacks									🟥	🟥	🟥	🟥	🟥	🟥		
WP4 – Phononic crystals (PnC)										🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
WP5 – Integration in biomedical application										🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪

Collaborations

A1: Application of advanced magnetic multilayers to SAW sensors

A6: Chemical and structural analysis of AlScN, synchrotron measurements

A8: Modeling of SAW sensor parameters and designs and phononic crystal

A10: Numerical studies on noise and phononic crystals

B1: Analog electronics, noise floor characterization, LOD measurements

B12(N), B13(N): Providing SAW sensors and measurement knowledge

Z1: Support in SAW sensor fabrication

Z2: Support with sensor characterization

Participation in focus groups

F1: Magnetic Layers

F3: Comparison of Sensor Concepts

F4: Magnetoelectric Sensors

Funds Requested

2 Doctoral researchers, consumables: 66 k€

[A9-1] Schell, V., Müller, C., Durdaut, P., Kittmann, A., Thormählen, L., Lofink, F., Meyners, D., Höft, M., McCord, J., & **Quandt, E.** (2020). Applied Physics Letters, 116(7).

[A9-2] Moench, S., Meyer, J. M., Zukauskaite, A., Lebedev, V., Fichtner, S., Su, J., Niekiel, F., Giese, T., Thormahlen, L**., Quandt, E.**, & **Lofink, F.** (2022). IEEE Sensors Letters, 6(10), 1–4.

[A9-3] Müller, C., Durdaut, P., Holländer, R. B., Kittmann, A., Schell, V., Meyners, D., Höft, M., **Quandt, E.**, & McCord, J. (2022). Advanced Electronic Materials, 8(6), Article 2200033.

[A9-4] Su, J., Fichtner, S., Ghori, M. Z., Wolff, N., Islam, M. R., Lotnyk, A., Kaden, D., Niekiel, F., Kienle, L., Wagner, B., & **Lofink, F.** (2022). Micromachines, 13(5).

[A9-5] Meyer, J. M., Schell, V., Su, J., Fichtner, S., Yarar, E., Niekiel, F., Giese, T., Kittmann, A., Thormählen, L., Lebedev, V., Moench, S., Žukauskaitė, A., **Quandt, E.**, & **Lofink, F.** (2021). Sensors, 21(24).

[A9-6] Wolff, N., Fichtner, S., Haas, B., Islam, M. R., Niekiel, F., Kessel, M., Ambacher, O., Koch, C., Wagner, B., **Lofink, F.**, & Kienle, L. (2021). Journal of Applied Physics, 129(3), Article 034103.

[A9-7] Schell, V., Spetzler, E., Wolff, N., Kienle, L., McCord, J., **Quandt, E.**, & Meyners, D. (2023). Scientific Reports, 13(1), 8446.

[A9-8] Kittmann, A., Müller, C., Durdaut, P., Thormählen, L., Schell, V., Niekiel, F., **Lofink, F.**, Meyners, D., Knöchel, R., Höft, M., McCord, J., & **Quandt, E.** (2020). Sensors and Actuators a: Physical, 311, 111998.

[A9-9] Durdaut, P., Müller, C., Kittmann, A., Schell, V., **Quandt, E.**, Knöchel, R., Höft, M., & McCord, J. (2021). Sensors, 21(16).

[A9-10] Samadi, M., Schmalz J., Meyer, J. M., **Lofink, F.**, Gerken M. (2023). Micromachines, 14(11), 2130.

[A9-P1] Kittmann, A.; Zabel, S.; Yarar, E.; Faupel, F.; Knöchel, R.; Höft, M.; Durdaut, P.; **Quandt, E.**: DE 10 2016 123 274 B4

[A9-P2] Fichtner, S.; Kaden, D.; Wagner, B.; **Lofink, F.**: DE 10 2018 203812